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#57

OPERATION AND SERVICE MANUAL

PROGRAMMABLE PICOAMMETER
MODEL 910A

MP MASTER
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OPERATION AND SERVICE MANUAL

PROGRAMMABLE PICOAMMETER

MODEL 910A

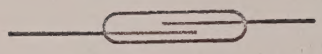
SYMBOLS AND ABBREVIATIONS

ADC	Analog-to-Digital Converter
AUTO	Automatic
a.c.	Alternating Current
amp (a)	Ampere
BCD	Binary Coded Decimal
BUG	Dual In-line Integrated Circuit
CCW	C ounterclockwise
CW	Clockwise
CMR	Common Mode Rejection
DAC	Digital-to-Analog Converter
DCU	Decimal Counting Unit
DEC	Decrease
DTL	Diode-Transistor Logic
db	Decibel
fempto (f)	10^{-15}
femptoamp (fa)	10^{-15} ampere
F/F	Flip-Flop
f.s.	Full Scale
Giga (G)	10^{9}
Gigaohm (GΩ)	10^{9} ohms
Hz	Cycles per Second
IGFET	Insulated Gate Field Effect Transistor
INC	Increase
Kilo (K)	10^{3}
KHz	10^{3} cycler per second
KΩ	10^{3} ohms
LSD	Least Significant Digit
MAN	Manual
MHz	10^{6} cycles per second
MSI	Medium Scale Integration
MSD	Most Significant Digit
Mega (M)	10^{6}

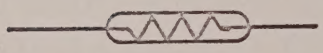
Symbols and Abbreviations, Cont'd.

MΩ	10^6 ohms
milli (m)	10^{-3}
millisecond (ms)	10^{-3} second
millivolt (mv)	10^{-3} volt
milliamp (ma)	10^{-3} ampere
micro (μ)	10^{-6}
microsecond (μs)	10^{-6} second
microvolt (μv)	10^{-6} volt
microamp (μa)	10^{-6} ampere
nano (n)	10^{-9}
nanoampere (na)	10^{-9} ampere
nanosecond (ns)	10^{-9} second
NBCD	Natural Binary Coded Decimal (1248)
NMR	Normal Mode Rejection
O.R.	Over Range
O.S.	One Shot
opamp	Operational Amplifier
pico (p)	10^{-12}
picoamp (pa)	10^{-12} amperes
pot	potentiometer
P.C.	Printed Circuit
REM	Remote
RMS	Root-Mean-Square
sec (s)	second
Tera (T)	10^{12}
Teraohm (TΩ)	10^{12}
v	volt
w	watt
°C	Degrees Cel
≃	approximately
Σj	Summing Junction
Ω	Ohm
%f.s.	percent of full scale
%r.	percent of reading

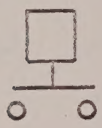
BLOCK DIAGRAM SYMBOLS



Reed relay



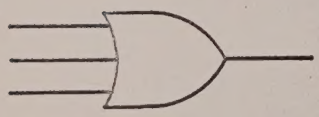
Hi-meg resistor (>10^7 Ω)



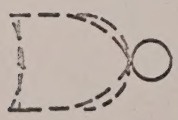
Pushbutton switch (N.O.)

Pushbutton switch (N.C.)

AND Gate



OR Gate

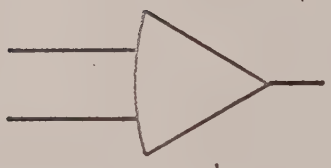


Inversion

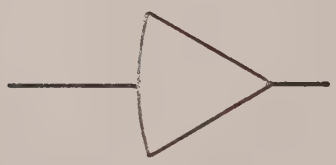
Screwdriver adjustment

Block Diagram Symbols, Cont'd.

A.C. coupled input (capacitor)



Differential operational amplifier



Single-ended inverting operational amplifier

SECTION I - GENERAL INFORMATION

1.1 Incoming Inspection

This instrument was inspected both mechanically and electrically before shipment. The instrument should be in operating condition upon receipt, however, the top cover should be removed and the instrument inspected for damage prior to applying power. There should also be packaged with the instrument the following items: Instruction Manual and the mating connectors for the ACCESSORY and PRINTER output (Amphenol 57-30240).

1.2 Mechanical Installation

The instrument can be operated as a bench top unit or rack mounted. Rack mounting ears are available from EG&G, Laboratory Products Division, 150 Aero Camino, Goleta, California, 93017.

Access for mounting the rack ears or chassis tracks is accomplished by snapping off the rear end caps (see Figure 1) and sliding the handle cover plate off. The rack mount ears are mounted to replace the front end caps.

IMPORTANT: On the most sensitive ranges, effects of mechanical vibration and input cable movement will generate noise currents. Care should be taken to minimize flexing of input cable and all types of vibration in general.

The use of low noise cable, such as Amphenol #21-537, will reduce the effects of cable flexing.

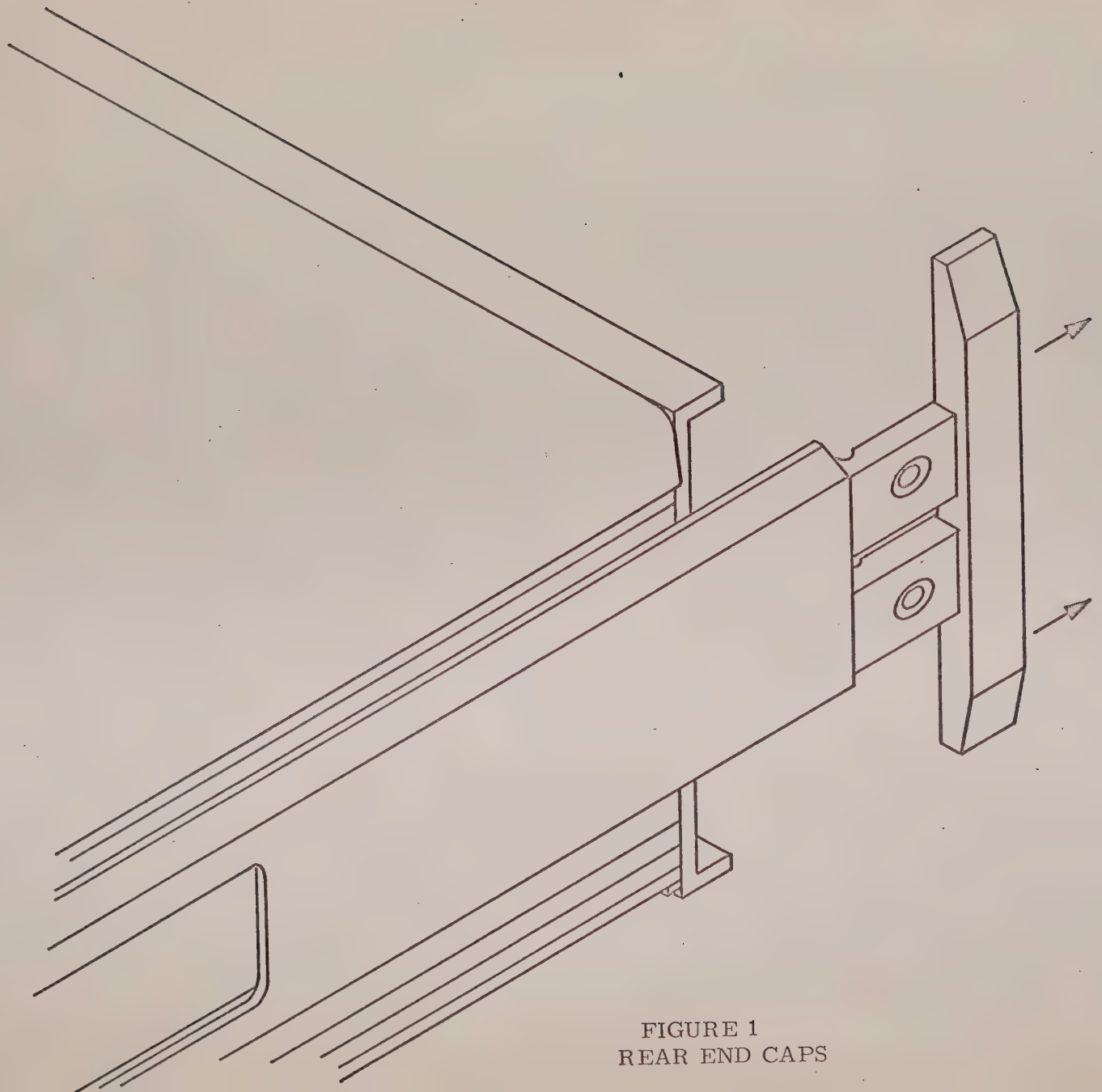


FIGURE 1
REAR END CAPS

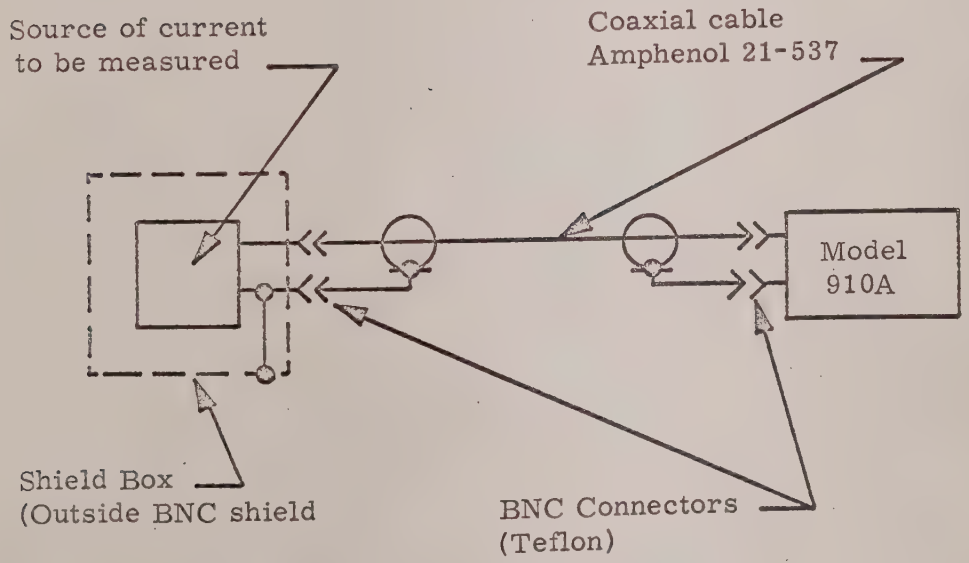
1.3 Electrical Connections

Power	105 - 125 volts, 50-60 Hz three wire service.
Input Connector	BNC type coaxial connecter. Recommended hook up cable is Amphenol #21-537 with teflon insulated connectors.

NOTE: To fully utilize the complete range of sensitivity, all connections, test fixtures, photomultipliers, systems, etc. must be shielded to eliminate or reduce the effects of power line radiation and/or physical movement of people or equipment. (See Figure 2.)

INPUT SHIELDING

FIGURE 2


Source of current to be measured
Coaxial cable Amphenol 21-537
Model 910A
Shield Box (Outside BNC shield
BNC Connectors (Teflon)

The chassis of the 910A is floating with respect to the BNC input connector. The voltage between chassis and the BNC connector shield must be maintained at less than 150 VDC or 115 VRMS 60 Hz for proper operation.

1.4 Input/Output Connections

Input/Output Connections are provided on two rear panel micro-ribbon connectors (Amphenol #57-3040). Table 8 lists the connections for the standard Model 910A. Connections for any Options will be found in OPTIONS, SECTION 6.

STANDARD INPUT/OUTPUT CONNECTIONS

TABLE 1

ACCESSORY CONNECTOR J 3	
Pin	
6	Bipolar Analog
	±5v F.S.
	(±10v O.R.)
7	Monopolar Analog
	0 to +5v F.S.
	(0 to 10v O.R.)
8	Analog Common
	Internal Power Supply
22	+15v
23	-15v
24	Com.

PRINTER CONNECTOR J-4		
Pin	Function	
8	Common	
7	Polarity	
	"+" = <1v	
	"-" = >6v	
12	8	Range Output
11	4	
10	2	
9	1	
5	1	Range Program
3	2	
2	4	
1	8	
4	Rem Com	

1.5 Repackage For Shipping

The following is a general fule for repackaging an instrument for shipment.

Place instrument in original container.

If substitute container is used:

a) Wrap instrument in heavy paper or plastic before placing in an inner container.

b) Use sufficient packing material around all sides of instrument and protect panel faces with cardboard strips.

c) Place instrument and inner container in a heavy carton or wooden box and seal with strong tape or metal bands.

d) Mark shipping container with "DELICATE INSTRUMENT - FRAGILE."

Accompanying the instrument should be information identifying the owner and indicating the service or repair to be accomplished. Include the Model Number and full Serial Number of the instrument.

SHIP TO: EG&G
Laboratory Products Division
P.O. Box 755
Goleta, California 93017

SECTION II - OPERATING INSTRUCTIONS

2.1 Front and Rear Panel Description

Following is a description of front and rear panel controls and indicators (Figures 3 and 4).

FIGURE 3

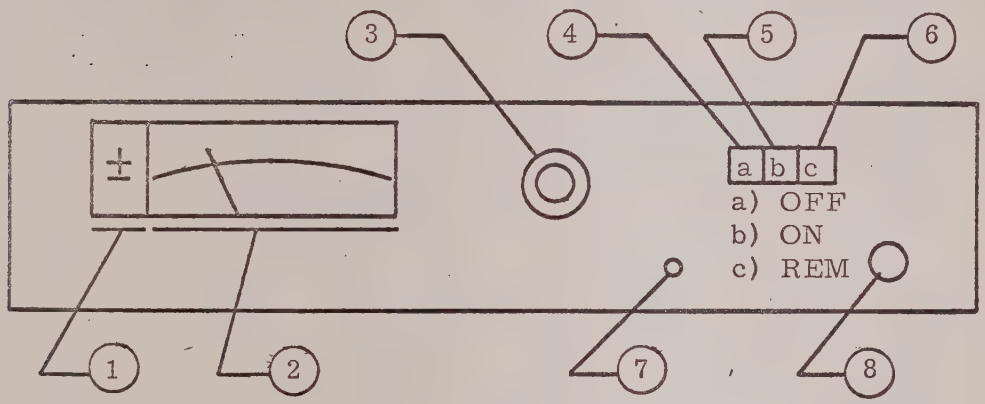
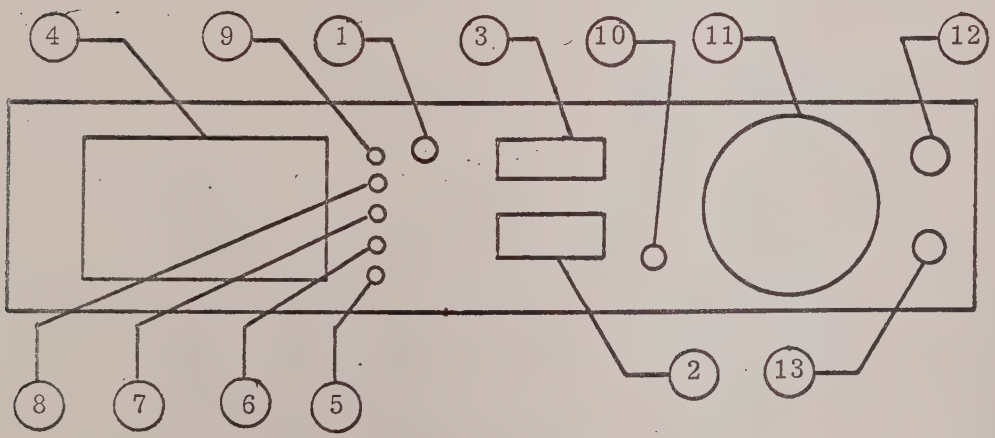


FIGURE 4



FRONT PANEL DESCRIPTION

(FIGURE 3)

①	POLARITY INDICATOR	Automatically indicates the polarity of the input current.
②	METER DISPLAY	Indicates the value of the current in amperes, 1.0 amperes full scale.
③	RANGE SWITCH	Number indicated is the decade range multiplier.
④	OFF	Turns instrument power off. The pushing of any of the function switches except OFF turns the instrument power on.
⑤	ON	Turns instrument power on.
⑥	REM	Enables remote programming of range.
⑦	ZERO	Adjustment for input voltage offset.
⑧	INPUT	Input connector with shielding cap (BNC).

REAR PANEL DESCRIPTION

(FIGURE 4)

(1)	BANDWIDTH	Bandwidth control for slower response and increased noise rejection. Maximum bandwidth is full CW.
(2)	ACCESSORY	Connector for analog outputs, power for Model 601A Calibrator and other accessories.
(3)	PRINTER	Connector for digital outputs.
(4)	CIRCULATION FAN EXHAUST	DO NOT RESTRICT AIR FLOW
(5)	-7	10^{-7}
(6)	-8	10^{-8}
(7)	-9	10^{-9}
(8)	-10	10^{-10}
(9)	-11	10^{-11}
(10)	INPUT	Optional rear input connector with shield cap (BNC).
(11)	CIRCULATION FAN	DO NOT RESTRICT AIR FLOW
(12)	FUSE	1-1/2 amp, 250 volt, Type 3 AG
(13)	POWER CORD	105 volt, 125 volt, 50-60 Hz, three wire service.

2.2 Operation

2.2.1 Turn-On and Zeroing

a) Connect the instrument to a grounded (three-wire) 105 - 125 volt 50 - 60 Hz outlet.

b) Push ON button and allow the instrument to warm up for 10 minutes.

c) Place shield cap on the input connector. Switch range to 10^{-2}.

d) Adjust the front panel ZERO control for an indicated polarity crossover.

This procedure will result in input voltage offset of 3mv or less.

The instrument is now ready for use.

2.2.2 Close Zeroing Procedure

a) Allow 1 hour for warm up.

b) Switch range to 10^{-2}.

c) Connect a short circuit between the BNC center conductor and shield. This procedure will display the input offset voltage multiplied by the input amplifier open loop gain. (The meter will probably indicate an overloaded condition.)

d) Center the Zero control between polarity cross-over. This procedure will allow adjustment of the input offset to less than 100μv.

2.2.3 Current Measurement

a) Perform Section 2.2.1.

b) Switch range to 10^{-2}.

c) Connect current to be measured to the INPUT with coaxial cable and teflon insulated BNC connectors. (See Section 1.3.)

d) Successively switch range CW in steps until the meter indicates between 0.1 and 1.0.

e) The magnitude and polarity of input current may now be read.

2.2.4 Noise in Operation

If, after checking for solid mechanical connections (no vibration) and PROPER SHIELDING, noise persists, the cause may be due to a noisy current source or excessive shunt input capacitance.

The reduction of this noise is possible by decreasing/increasing the bandwidth/risetime with the BANDWIDTH control on the rear panel. Full clockwise (CW) is maximum bandwidth, i.e., the further counter-clockwise (CCW) the control is turned, the more effective the noise reduction becomes.

2.2.5 Bandwidth Control Adjustment

a) Turn the bandwidth (BW) control full CCW.

b) Follow the procedure for Manual operation.

c) Turn the BW control full CW.

d) Advance the BW control CCW until the observed noise is acceptable.

2.3 Remote Control Connections

Range switching may be remotely programmed and monitored. Programming is single point control to a remote common wire provided at the PRINTER connector.

2.3.1 Connections

Mating connectors are Amphenol #57-30240. Programming is single point control from four BCD lines to a remote common wire provided at the PRINTER connector.

TABLE 2

BCD LINES	PRINTER CONNECTOR PIN NUMBER
8	1
4	2
2	3
1	5
Remote Program Common	4

Table 3 indicates the programming code.

X indicates connection to remote common

O indicates open circuit

TABLE 3

Range	1	2	4	8
10^{-2}	O	O	O	O
10^{-3}	X	O	O	O
10^{-4}	O	X	O	O
10^{-5}	X	X	O	O
10^{-6}	O	O	X	O
10^{-7}	X	O	X	O
10^{-8}	O	X	X	O
10^{-9}	X	X	X	O
10^{-10}	O	O	O	X
10^{-11}	X	O	O	X

2.3.2 Remote Indication

BCD output lines are available at the PRINTER connector for remote range indication. (See Table 4.)

REMOTE RANGE INDICATION

TABLE 4

BCD LINES	PRINTER CONNECTOR PIN NUMBER
8	12
4	11
2	10
1	9
Common	8

Table 5 indicates the output code.

TABLE 5

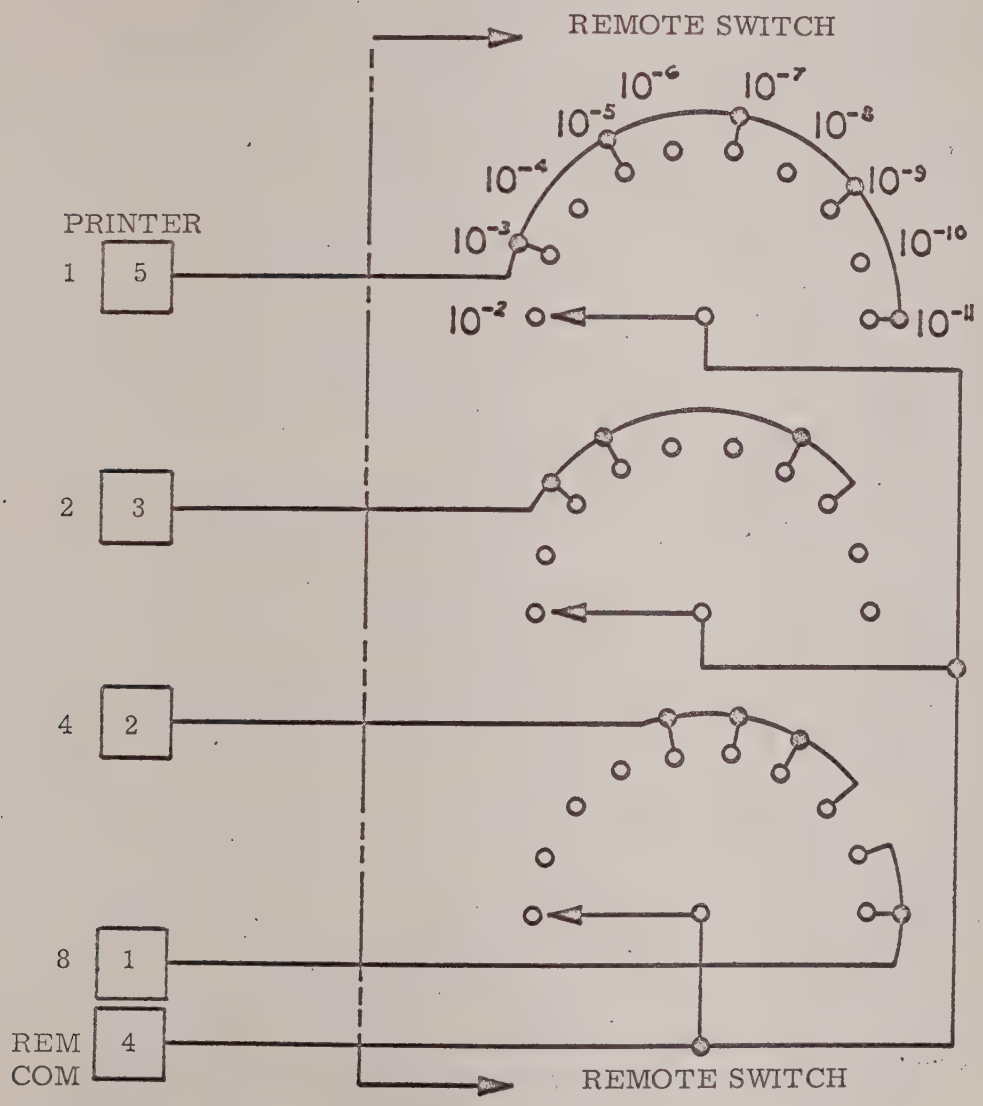
	BCD LINES			
Range	1	2	4	8
10^{-2}	0	0	0	0
10^{-3}	1	0	0	0
10^{-4}	0	1	0	0
10^{-5}	1	1	0	0
10^{-6}	0	0	1	0
10^{-7}	1	0	1	0
10^{-8}	0	1	1	0
10^{-9}	1	1	1	0
10^{-10}	0	0	0	1
10^{-11}	1	0	0	1

1 = +.7 volts (2ma sink)

0 = +15 volts (6.6 KΩ source)

FIGURE 5

A remote switching scheme may be as follows:



Active Function	Switch closure or saturated NPN transistor (+.2v max.), 2ma sink
Inactive Function	Open circuit, +15 volts

SECTION III - DESCRIPTION AND SPECIFICATIONS

3.1 General Description

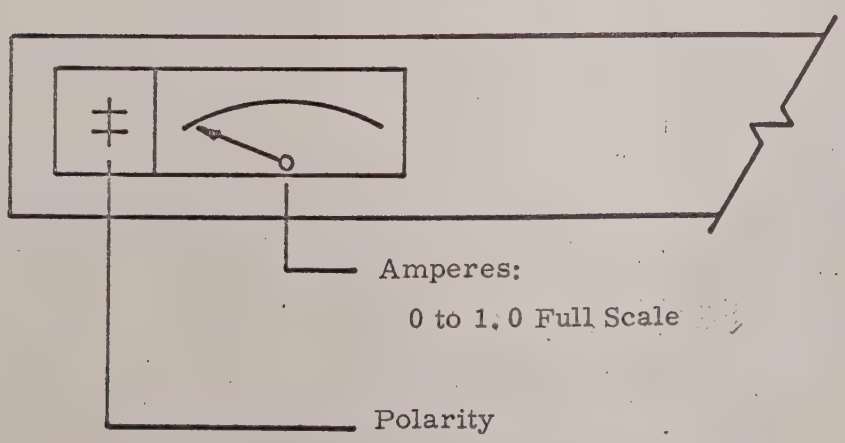
The EG&G Model ME-910 Programmable Picoammeter is of all solid state construction and has the capability of measuring positive or negative direct current from ± 10ma to ±10 picoamps full scale in ten inclusive decade ranges. Range changing is accomplished manually either from the front panel or programmed remotely in decade steps with four (4) BCD lines. Polarity determination is automatic.

Outputs are provided for analog recording of current value either monopolar (0 to 5 full scale independent of polarity) or bipolar (-5v to +5v full scale, polarity opposite to input current).

3.2 Display Format

The display consists of one neon glow tube for display of polarity and a 3-3/4" 1% meter movement for current. Range is determined by the position of the range switch or BCD Code applied in the REM position.

FIGURE 6



3.3 Specifications

3.3.1 Ranges

Full scale ranges are in ten (10) inclusive decade steps from 10^{-2} amperes to 10^{-11} amperes.

3.3.2 Polarity

Positive polarity is conventional current into the center conductor of the BNC input connector. Polarity selection is automatic with a response time of less than 250ms for ±5% full scale input step function. Polarity is displayed on the front panel by a neon glow tube. A digital output is provided for remote polarity monitoring.

3.3.3 Accuracy

Accuracy is specified when measured at the analog output as the worst-case errors accumulated when calibrated according to the procedure outlined in this Instruction Manual. These specifications are valid at 25° C ±1° C, 50% relative humidity for one month after calibration.

Accuracy does not include effects of input voltage offset, current offset. The temperature coefficient for each range is given in 3.3.3.1.

TABLE 6

Range	Accuracy - % R.S.	Note
10^{-2} thru 10^{-6}	.2	Fixed ranges, not adj.
10^{-7}	.45	Ranges adjustable to stated accuracy under stated conditions with EG&G Model TF-601 Calibrator
10^{-8}	.6	
10^{-9}	.8	
10^{-10}	1.0	
10^{-11}	1.2	

3.3.3.1 Range Accuracy Temperature Coefficient

TEMPERATURE COEFFICIENT

TABLE 7

Range	T.C. PPM/°C
10^{-2} thru 10^{-6}	±100
10^{-7}	±300
10^{-8} thru 10^{-11}	±1000

3.3.4 Input Offsets

3.3.4.1 Voltage Offset

T.C.	±150μv/°C, 5°C, to 50°C
Drift	<3 mv in one week after on hour warm-up
Adjustment	To within 50μv of zero

3.3.4.2 Current Offset

T.C.	$\pm 5 \times 10^{-15}$ a/°C, 5°C to 35°C
Steady State	10^{-13} a max., 5×10^{-14} typ.

3.3.5 Input Resistance

The maximum input resistance and corresponding voltage drop for full scale input current is given in Table 3.

INPUT RESISTANCE

TABLE 8

Range	Input Resistance	Voltage Drop
10^{-11}	5 M	50μv
10^{-10}	500 K	50μv
10^{-9}	50 K	50μv
10^{-8}	5 K	50μv
10^{-7}	500	50μv
10^{-6}	50	50μv
10^{-5}	5	50μv
10^{-4}	.5	50μv
10^{-3}	.1	50μv
10^{-2}	.1	50μv

3.3.6 Input Isolation

The BNC input connector to the 930A is isolated from the chassis and power line with approximately 1200pf in parallel with 100 megohms. A maximum difference in potential of ±150v or 115v RMS, 60 Hz can be sustained between the input connector and chassis with no change in specifications.

3.3.7 BANDWIDTH/RESPONSE TIME

TABLE 9

	Analog Output Response		
Range	Bandwidth (Hz)	Time Constant (63%)	Rise Time (10%-90%)
10^{-11}	1.3	120ms	270ms
10^{-10}	10	15ms	32ms
10^{-9}	40	3ms	10ms
10^{-8}	390	400µs	900µs
10^{-7}	850	270µs	400µs
10^{-6}	2 K	80µs	180µs
10^{-5} - 10^{-2}	2.5K	60µs	180µs

NOTE: Specifications in Table 9 are not appreciably affected for shunt capacitive loading up to 3000 pf.

3.3.7.1 Effect of BANDWIDTH Control

BANDWIDTH CONTROL CHARACTERISTIC

TABLE 10

	10%-90%	Rise Time
Range	Full CCW	50% CCW
10^{-11}	25 sec.	12 sec.
10^{-10}	2.5 sec.	1.2 sec.
10^{-9}	300ms	140ms
10^{-8}	35ms	16ms
10^{-7}	4ms	1.8ms
10^{-6}	700µs	
10^{-5} - 10^{-2}		

3.3.8 Overload

ABSOLUTE MAXIMUM INPUT

TABLE 11

Range	Maximum Input
10^{-11} thru 10^{-7}	500 volts
10^{-6} thru 10^{-2}	220 ma

3.3.9 Outputs

3.3.9.1 Analog Output

Bipolar Analog	±5v F.S. 2 ma maximum Polarity opposite to input
Monopolar Analog	0 to +5v F.S. 1 ma maximum

3.3.10.2 Digital Output

Polarity	Single Line Binary, diode coupled Negative Polarity: > + 6v behind 3.3K Positive Polarity: < + 1v 2 ma sink

3.3.11 Remote Programming

Remote programming is single point control, i.e., each programmed function is controlled by a single program line. Remote programming is possible only when instrument is switched to REM function.

3.3.11.1 Remote Control Requirements

Active Function	Switch closure between control line and remote common line or saturated NPN transistor.
Inactive Function	Open circuit between control line and remote line or cut off NPN transistor.

3.3.12 Environment

Temperature	$5^{\circ}C$ - $50^{\circ}C$
Humidity	0 - 50% relative humidity

4.1 Discussion on Current Measurement - Shunt and Operational

The measurement of direct coupled current to sensitivities less than 1 picoampere has generally been accomplished by two methods:

a) Shunt, or electrometer method

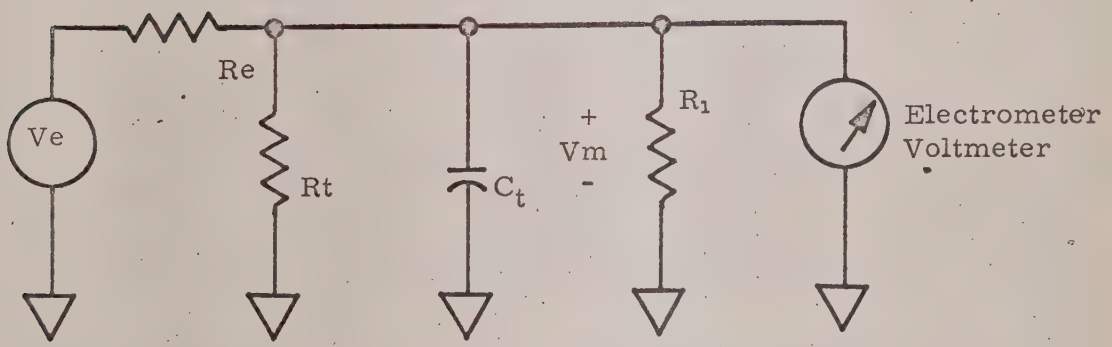
b) Operational method

4.1.1 Shunt Analysis

The Shunt Method is simply the application of a high input resistance voltmeter (electrometer) in measuring the voltage drop across a high value resistor (Figure 7).

SHUNT MEASUREMENT MODEL

FIGURE 7



Where: Ve and Re - Thevenin equivalent voltage and resistance

R_1 - Shunt dropping resistor

R_t - Total leakage resistance - cable, electrometer, and connectors

V_m - Voltage drop measured by the electrometer

C_t - Total stray capacitance of cable, source, etc.

Solving for V_m:

$$V_m = \frac{Ve}{Re} R_1 \left[\frac{1}{1 + \frac{R_1}{Re} + \frac{R_1}{R_t}} \right] \qquad (1)$$

Two inequalities may be applied to this expression:

$R_t >> R_1$ (effect of shunt leakage with respect to the dropping resistor is negligible).

$R_e >> R_1$ (circuit loading is negligible*).

The application of these inequalities simplifies the general expression and reveals the effects of leakage and loading. When $R_t >> R_1$, $R_e >> R_1$

$$V_m \tilde{=} \frac{Ve}{Re} R_1 \left[1 - \left(\frac{R_1}{Re} + \frac{R_1}{Rt} \right) \right] \qquad (2)$$

The term in brackets may be interpreted as an error term consisting of contributions by leakage $\frac{R_1}{R_t}$ and loading $\frac{R_1}{R_e}$

For example, suppose

$V_e = 1$ volt

$R_e = 10^{12}$ ohms

$R_1 = 10^{10}$ ohms

$R_t = 5 \times 10^{13}$ ohms

$V_m = .01\ [1 - .01 - .002]$ volts

The error contributed by leakage and loading is slightly in excess of 1%.

The effects of electrometer offset and the precision of R_1 become immediately evident - offset and 1 mv causes a 10% error and the inaccuracy of R_1 is directly related to an equal inaccuracy at the voltmeter input.

---

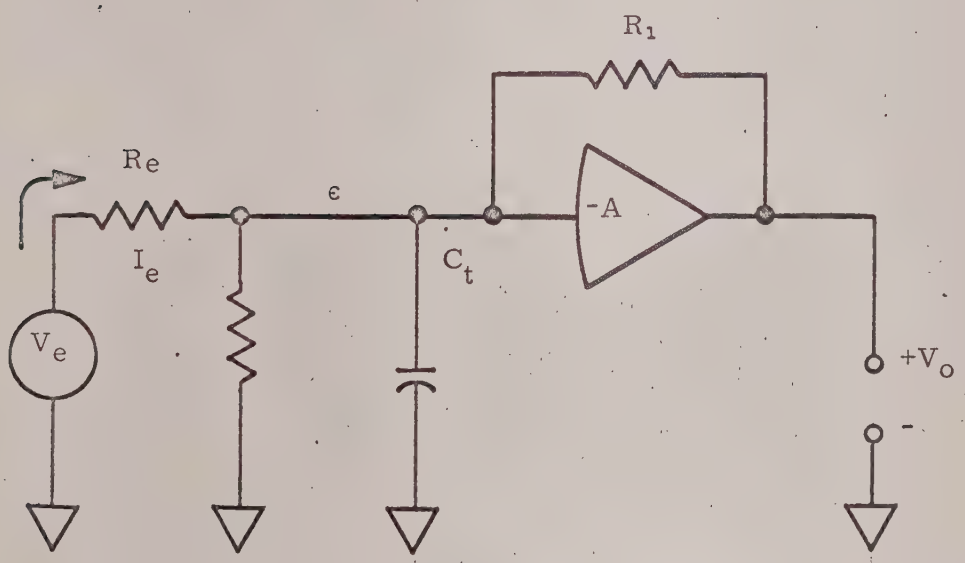
*The dual of a voltage measurement where it is desireable to maintain $R_1 >> R_e$.

In addition, the large value of input resistance ($10^{10}\,\Omega$) has a serious effect on bandwidth, i.e., 100 pf of C_t will cause a 2.35 second 10% - 90% response to a step input.

4.1.2 Operational Analysis

The operational method is the application of a low leakage operational amplifier with resistive feedback to achieve the same end - measurement of low level direct coupled current.

OPERATIONAL MEASUREMENT MODEL
FIGURE 8



Where: V_e, R_e, R_t, C_t have the same definition as in Shunt analysis (Figure 8)

R_1 - Voltage dropping resistor now inserted in the feedback of an operational amplifier

-A - Open loop gain of the amplifier

ϵ - Summing junction voltage

V_o - Amplifier output voltage

The DC node equation at the summing junction:

$$\epsilon (G_e + G_t + G_1) - V_e G_e - V_o G = O_1 \qquad (3)$$

also,

$$V_o = -A\epsilon$$

combining and rearranging

$$-Vo = Ve \frac{R_1}{Re} \left[\frac{1}{1 - \frac{1}{A} (1 + \frac{R_1}{Re} + \frac{R_1}{R_t})} \right] \qquad (4)$$

for $A >> 1$

$$-Vo = Ve \frac{R_1}{Re} \left[1 - \frac{1}{A} (1 + \frac{R_1}{Re} + \frac{R_1}{R_t}) \right] \qquad (5)$$

Note that the error term is similar to that obtained for the shunt method, with the exception that the effects are reduced by the open loop gain of the operational amplifier. In fact, if (2) and (3) are satisfied, the error term approaches simply

$$(1 - \frac{1}{A}).$$

Applying the same circuit parameters as in the shunt example:

V_e - 1 volt
R_e - 10^{12}
R_1 - 10^{10}
R_t - 5×10^{13}
A - 20,000

Solving for V_o:

$$-V_o \simeq .01 \left[1 - (\frac{.01 + .002 + 1}{20,000}) \right] \qquad (6)$$

Thus, in the same application, the operational method has reduced the error from 1% to less than .01%. Amplifier offset* and the precision of R_1 contribute to error as in the shunt example.

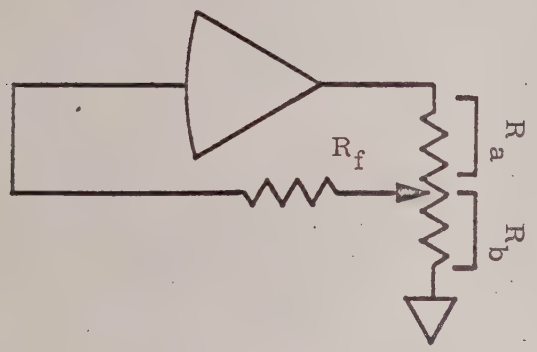
---

*See Section 4.2

The inaccuracy of R_1 may be simply adjusted with a potentiometer in the feedback loop:

VARIABLE FEEDBACK

FIGURE 9



Where now the effective feedback resistor becomes:

$$R_1 \text{ (effective)} = R_f \left(\frac{R_a}{R_b} + 1\right) + R_a$$

Thus the variations in large value resistors may be easily adjusted by the ratio of $R_a : R_b$.

4.1.2.1 Input Resistance

Referring to Figure 8, the Norton equivalent source current is:

$$I_e = V_e G_e \tag{7}$$

Also,

$$R_{in} = \frac{\epsilon}{I_e} \quad \text{(assuming the leakage is negligible)} \tag{8}$$

Rearranging

$$\epsilon = \frac{V_e G_e}{G_e + G_t + G_1 + AG_1} \tag{9}$$

And for $A \gg I$

$$\Rightarrow R_{in} \frac{R}{A} \left[1 - \frac{1}{A}\left(\frac{R_1}{R_e} + \frac{R_1}{R_t}\right)\right] \tag{10}$$

For all practical purposes,

$$R_{in} \cong \frac{R}{A} \qquad (11)$$

Again, a reduction by the open loop gain.

For a 2.35 second 10% - 90% risetime as in the shunt case the C_t would have to be increased by 20,000 to 2μf.

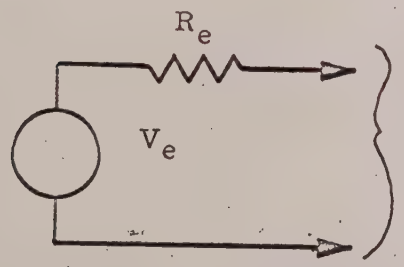
4.1.3 Summary

All circuit parameters being equal, the obvious improvements realized by the operational method of current measurement are:

1) Lower input resistance
   a) Reduction in source loading
   b) Faster response time
   c) Less emphasis need be placed on extremely high leakage resistance at the input
2) Low current measuring instruments may be easily calibrated for variations in large value resistors.

4.2 EFFECT OF INPUT VOLTAGE OFFSET AND SOURCE RESISTANCE

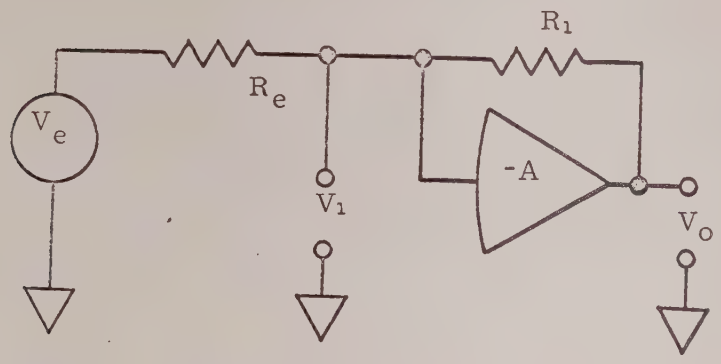
A source of current may be reduced to:



Current Source

Where: V_e and R_e are the familiar Thevenin equivalent voltage and resistance.

This circuit in turn may be connected to an operational type current-to-voltage converter:



Where: A is the amplifier open loop gain (assumed to approach ∞ for this example).

R_1 is the feedback (transfer function) resistor

V_1 is the fixed summing junction offset

V_o is the amplifier output voltage

Writing the node equation at the summing junction:

$$V_1 (G_e + G_1) - V_e G_e - V_o G_1 = o \qquad (12)$$

Rearranging:

$$-V_o = \frac{V_e}{R_e} R_1 - V_1 \left(\frac{R_1}{R_e} + 1\right) \qquad (13)$$

The first term in the equation is the desired output, the second term being an error contributed by V_1

Define:

$$\frac{V_e}{R_e} R_1 \triangleq V_{ot} \text{ (true output)} \qquad (14)$$

Then the % error contributed by V_1:

$$\% \text{ error} = \left(\frac{V_1}{V_e} + \frac{V_1}{V_{ot}}\right) X\ 100 \qquad (15)$$

The error term may be interpreted as follows:

The error true to summing junction offset is minimized by:

a) Keeping the ratio of offset to equivalent source voltage small.

b) Keeping the ratio of offset to full scale output small.

The second term would be evident with no input source by an output equal to V_1. The first term usually predominates in most applications.

In practice, the close zeroing procedure of the 930A reduces error due to the second term to less than .002% f.s. At the same time, the source voltage would have to be less than 100mv in order to cause an error of .1% due to the first term.

4.3 Input Circuitry and Range Changing

4.3.1 Input Amplifier

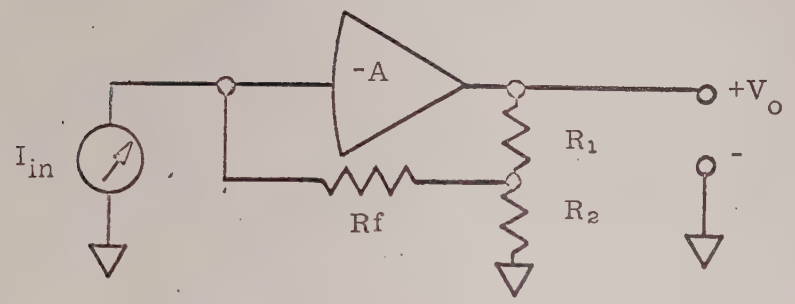
The input amplifier consists of a high gain IG FET operational amplifier with the range changing feedback resistors switched by reed relays. An operational amplifier with resistive feedback as in Figure 10 will exhibit a transfer function:

$$Z_{21} = \frac{-V_o}{I_n} = R_f \frac{R_1}{R_2} + 1 + R_1,$$

Providing the open loop gain is infinite and input offset voltage and current are zero.

VARIABLE FEEDBACK

FIGURE 10



In a practical circuit these three conditions are never met and depending on the degree to which they are approached, will dictate the performance of this type of current to voltage converter.

Calibration of the input amplifier is accomplished by adjusting the ratio of $\frac{R_1}{R_2}$.

Since replacement of Hi-megohm resistors is eliminated, periodic calibration may be performed in a more straight forward manner.

4.3.3 Block Diagram

A simplified block diagram of the input amplifier and range control is shown in Figure 11.

Current applied to the input of the IG FET amplifier (A1) will result in an output voltage according to:

$$Vo \cong -I_{in} \times Rf \left(\frac{R_1}{R_2} + 1 \right)$$

The full scale output of A_1 is +5v to -5v for negative and positive full scale inputs, respectively. This output voltage is connected to an absolute value circuit. This circuit senses the output polarity for negative voltages and passes the voltage straight through for positive voltages. This converts a bipolar (-10v to +10v) signal out of A_1 to a unipolar (0v to +10v) signal at the absolute value output. The polarity sensing circuit also illuminates the correct polarity sign on the front panel indicator.

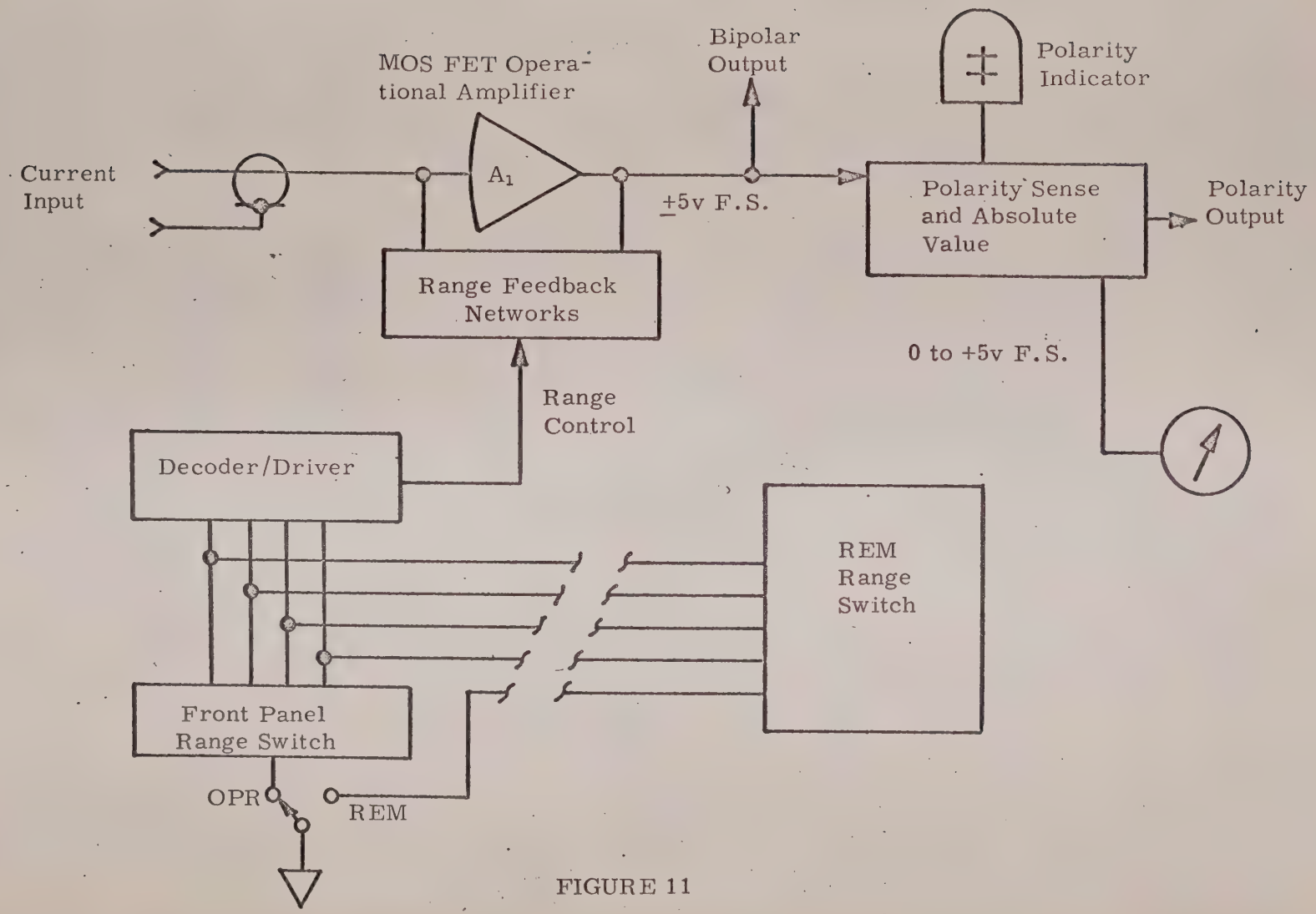

MOS FET Operational Amplifier
Bipolar Output
Polarity Indicator
Current Input
A1
±5v F.S.
Polarity Sense and Absolute Value
Polarity Output
Range Feedback Networks
0 to +5v F.S.
Range Control
Decoder/Driver
REM Range Switch
Front Panel Range Switch
OPR
REM

FIGURE 11

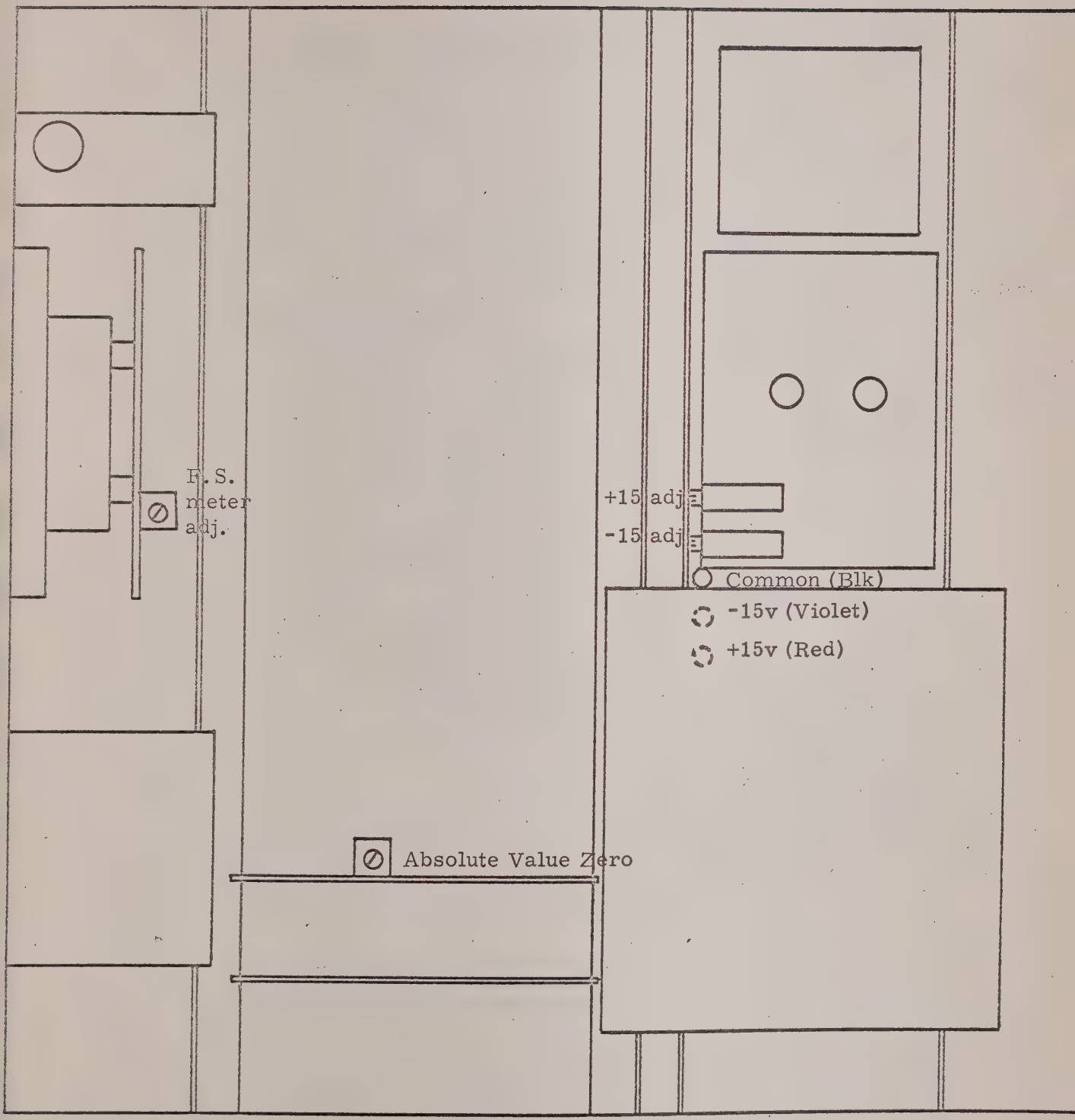

F.S.
meter
adj.
+15 adj
-15 adj
Common (Blk)
-15v (Violet)
+15v (Red)
Absolute Value Zero

FIGURE 12

SECTION V - CALIBRATION

5.1 Internal Instrument Adjustments

5.1.1 Test Equipment Required

1) Power Supply - Short term stability ±.02% or better for 20 volts output @ 200μa.
2) Digital Voltmeter - Accuracy ±.02% or better.
3) Resistor - 100K, ±5%.

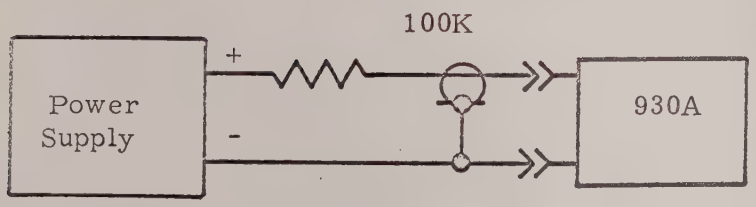
5.1.2 Power Supply Adjustment

Power supply accesses and adjustments are shown in Figure 13. Tolerance on ±15 volt supplies is ±30mv. Adjustment requires removal of card retainer plate. ±185 volt power supply tolerance is ±15 volts with no adjustment provided.

5.1.3 Absolute Value Zero Adjustment

1) Connect the test equipment as in Figure 13.
2) Remove the 910A top cover.

TEST EQUIPMENT CONNECTION
FIGURE 13



3) Connect the 910A to a 105-125 volt 50 - 60 Hz threewire outlet.
4) Depress the OPR pushbutton, allow 10 minutes for warm up.
5) Connect the DVM common to Pin 8 on the rear panel ACCESSORY connector.

6) Apply power to the power supply. Adjust the power supply controls to +10 volts.

7) Connect the DVM input to Pin 6 on the ACCESSORY connector. Record the reading.

8) Connect the DVM input to Pin 7 on the ACCESSORY connector.

9) Adjust the ABSOLUTE VALUE ZERO potentiometer for the same DVM indication (±1mv) as in Step 7. Note that the polarity is Negative in Step 7 and Positive in Steps 8 and 9.

5.1.4 Meter Calibration

1) Turn off instrument.

2) Adjust front panel meter zero, tapping meter face to insure proper adjustment.

3) Follow steps 1 through 4 as in the Absolute Value Zero adjustment.

4) Connect the DVM to Pin 7 on the ACCESSORY connector.

5) Switch range to 10^{-4}.

6) Adjust the power supply to indicate +5.0 volts ±1mv on the DVM. (Approximately 10v on the power supply).

7) Adjust the Full Scale Meter Adjustment to indicate precisely 1.0 on the meter, tapping the face to insure proper adjustment.

5.2 Range Calibration

Theory of Bootstrap Calibration

The basis of bootstrap calibration is dependent upon the accurate Division of Current, not the accurate Generation of Current.

One boostrap step may be outlined:

1) Measure an unknown current with a precision wire wound resistor.

2) Divide that current by exactly 10 (or the factor of sensitivity increase to the next range).

3) Use the divided current to adjust the next most sensitive range.

Successive bootstrap steps use the newly adjusted ranges to measure a new unknown current until all ranges are calibrated.

In essence, bootstrap calibration eliminates the weak link in the resistive calibration of picoammeters:

BOOTSTRAP CALIBRATION DOES NOT DEPEND IN ANY WAY ON THE LONG TERM STABILITY OF HI-MEG RESISTORS.

The bootstrap is subject to the following inaccuracies:

1) Precision of the current measurement (Step 1).
2) Voltage coefficient* of the current source when dividing (Step 2).
3) Accuracy of the adjustment (Step 3).
4) Input amplifier voltage and current offset (affects all three steps).

The Model 930A accuracy specifications include these contributions to error in the worst accumulative case using the EG&G Model 601A as a calibration source.

5.2.1 Test Equipment Required

EG&G Model 601A - 01 Calibration
Digital voltmeter - Accuracy .05% or better

5.2.2 Procedure

1) Connect the DVM to the ACCESSORY connector:
   Input - Pin 6
   Common - Pin 8

---

*Voltage coefficient of the EG&G Model 601A is kept to a minimum by use of 50 PPM/volt HI-MEG resistors.

2) Turn the BANDWIDTH control on the 910A to the center of its travel. Front panel pushbuttons to OPR, range to 10^{-8}. Allow 30 minutes for warm up.

3) Set the 601A-01 controls:
   a) Current - "-"
   b) Range - 10^{-7}
   c) Multiplier - 10
   d) Variable - approximately centered

4) Perform Section 3.2.2 on 910A.

5) Connect a two-foot section of Amphenol 21-537 coaxial cable with teflon BNC connectors between the 601A current output connector and the 910A input. (Meter might indicate an overload.)

10^{-7} range cal.

6) Record DVM indication.

7) 601A Multplier to 1.

8) 910A range one decade more sensitive, to 10^{-7}.

9) Adjust 910A "-7" calibration pot for same indication as in Step 6.

10^{-8} range cal.

10) 601A range to 10^{-8}, Multiplier to 10.

11) Record DVM indication.

12) 601A Multiplier to 1.

13) 910A range to 10^{-8}.

14) Adjust 910A "-8" calibration pot for Step 11 indication.

10^{-9} range cal.

15) 601A range to 10^{-9}, Multiplier to 10.

16) Record DVM indication.

17) 601A Multiplier to 1.

18) 910A range to 10^{-9}.

19) Adjust 910A "-9" calibration pot for Step 16 indication.

10^{-10} range cal.

20) 601A range to 10^{-10}, Multiplier to 10.

21)* Record DVM indication.

22) 601A Multiplier to 1.

23) 910A range to 10^{-10}.

24) Adjust 910A "-10" calibration pot for Step 21 indication.

10^{-11} range cal.

25) 601A range to 10^{-11}, Multiplier to 10.

26) Record DVM indication.

27) 601A Multiplier to 1.

28) 930A range to 10^{-11}.

29) 601A current to off.

30) Allow 40 seconds for settling. Adjust front panel 910A Zero to indicate 0 $\pm$5mv on DVM, if necessary.

31) 601A current to "-".

32) Allow 40 seconds for settling. Adjust "-11" calibration pot for Step 26 indication.

EG&G

MP MASTER

MA29058